EI 7
(282/1960)

UDC 621.372.413 : 621.318.1

ACTA POLYTECHNICA SCANDINAVICA

ELECTRICAL ENGINEERING SERIES No. 7

E. V. Sørensen

CAVITY MEASUREMENTS OF THE TE_{11}

Propagation Constants of a
Circular Waveguide Containing
a Magnetized Ferrite Rod

Danish Contribution No. 8
COPENHAGEN 1960

ACTA POLYTECHNICA SCANDINAVICA

... a Scandinavian contribution to international engineering sciences

Published under the auspices of the Scandinavian Council for Applied Research

in *Denmark* by the Danish Academy of Technical Sciences

in *Finland* by the Finnish Academy of Technical Sciences, the Swedish Academy of Engineering Sciences in Finland, and the State Institute for Technical Research

in *Norway* by the Norwegian Academy of Technical Science and the Royal Norwegian Council for Scientific and Industrial Research

in *Sweden* by the Royal Swedish Academy of Engineering Sciences, the Swedish Natural Science Research Council, and the Swedish Technical Research Council

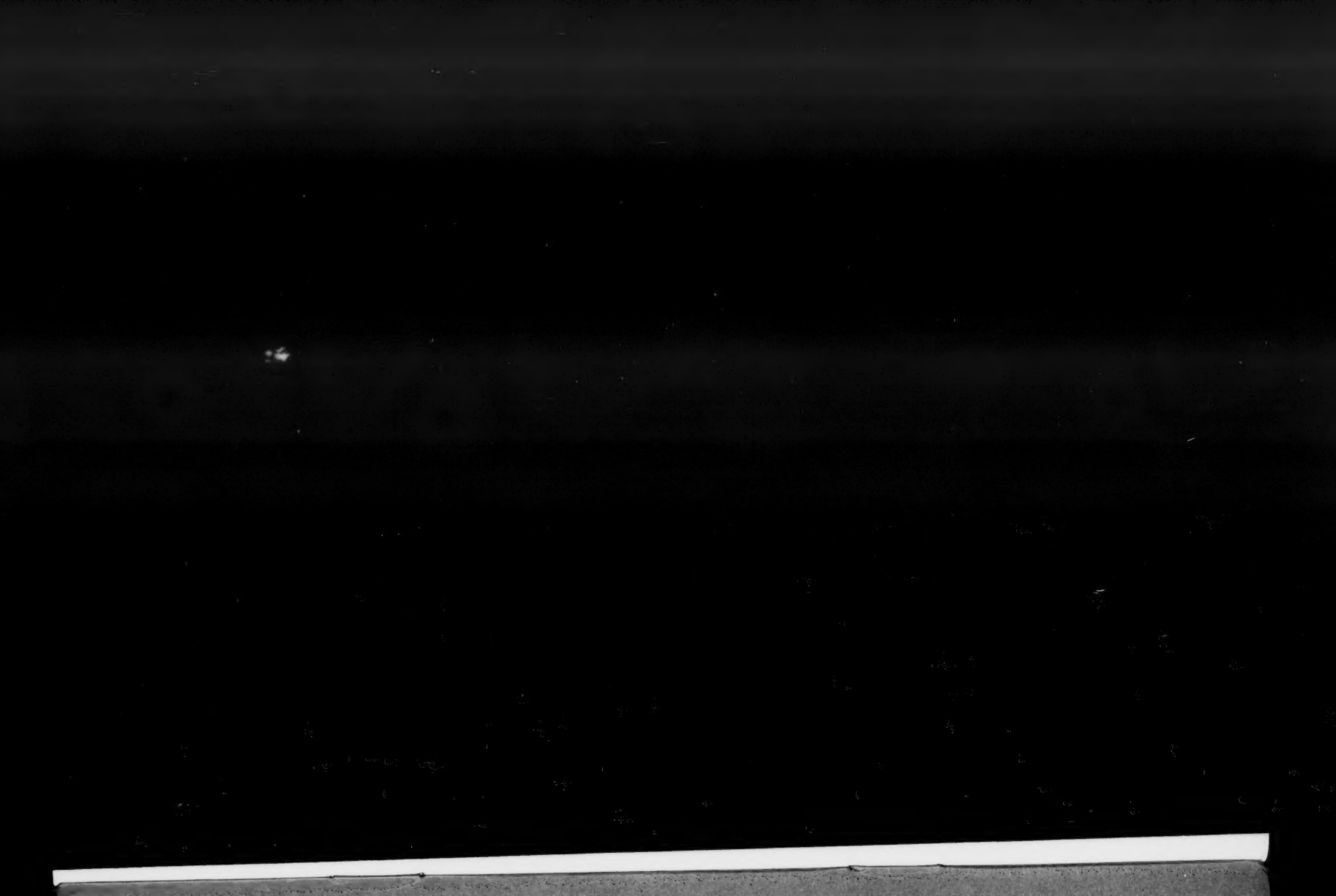
Acta Polytechnica Scandinavica consists of the following sub-series:

Chemistry including Metallurgy Series, Ch
Civil Engineering and Building Construction Series, Ci
Electrical Engineering Series, El
Mathematics and Computing Machinery Series, Ma
Mechanical Engineering Series, Me
Physics including Nucleonics Series, Ph

For subscription to the complete series or to one or more of the sub-series and for purchase of single copies, please write to

ACTA POLYTECHNICA SCANDINAVICA PUBLISHING OFFICE
Box 5073
Stockholm 5 Phone 61 47 53

This issue is published by
THE DANISH ACADEMY OF TECHNICAL SCIENCES
Copenhagen, Denmark



UDC. 621.372.413 : 621.318.1

CAVITY MEASUREMENTS OF THE TE_{11} PROPAGATION CONSTANTS OF A CIRCULAR WAVEGUIDE CONTAINING A MAGNETIZED FERRITE ROD

E. V. Sørensen
Microwave Laboratory
Danish Academy of Technical Sciences

ACTA POLYTECHNICA SCANDINAVICA
Electrical Engineering Series, No. 7
(AP 282, 1960)

SUMMARY

The propagation constants for circularly polarized TE_{11} fields in a circular waveguide containing a longitudinally magnetized ferrite rod have been measured at 4600 Mc/s for various low magnetization ferrites. A tunable cavity method originally described by van Trier has been employed with some refinements. The saturation magnetization, the dielectric constant and the isotropic permeability of the ferrite when it is demagnetized, have been calculated from the results by means of the first-order perturbation solution of the phase constant. The saturation magnetization thus found is in fairly good agreement with the value measured direct by means of a ballistic fluxmeter.

The figure of merit i. e. the maximum value of the ratio of Faraday rotation to insertion attenuation, has been derived from the measurements and compared to the theoretical figure of merit as derived by B. Lax and based on the assumption of a Lorentzian resonance line shape. A vast disagreement was found in that the measured figures of merit were by between one and two orders of magnitude higher than the theoretical ones. This may be connected with the fact that the resonance lines for the ferrites are unsymmetrical, the losses at the low-field side of resonance dropping faster than those at the high-field side. This is a common phenomenon in polycrystalline ferrites.

For this reason it is felt that the theoretical figure of merit referred to above leads to a far too pessimistic judgement of the applicability of polycrystalline ferrites to Faraday rotation devices.

CONTENTS

		Page
1.	Introduction	1
2.	Theory of Experimental Technique.....	2
3.	Derivation of the Dielectric Constant, the Saturation Magnetization and the Isotropic Permeability in the Case of Zero Magnetization	4
4.	Experimental Procedure	7
5.	Results of Measurements	10
6.	Discussion on the Figures of Merit of the Ferrites..	14

Appendix I

Special Problems regarding the Test Cavity and the Solenoid Magnet. 17

The report includes 4 figures, 11 graphs and 2 tables.

CAVITY MEASUREMENTS OF THE TE_{11} PROPAGATION CONSTANTS OF A CIRCULAR WAVEGUIDE CONTAINING A MAGNETIZED FERRITE ROD

E. V. Sørensen
Microwave Laboratory
Danish Academy of Technical Sciences

1. Introduction

In determining the applicability of ferrite materials to microwave components, the problem of choosing the most descriptive parameters arises. No single figure of merit which covers all or only the most important applications can be established. It is true, that theoretical figures of merit based on the gyromagnetic linewidth have been derived for different ferrite devices (ref. 1.2.), but they all rest upon the assumption of a Lorentzian line shape, which appears to be inappropriate in many cases.

Thus if experimentally determined linewidths are used in these expressions, a too pessimistic estimate of the utility of the ferrites in devices operating on the low-field side of resonance (Faraday rotators, phase shifters etc.) will be obtained whereas the estimate becomes too optimistic for ferrites in resonance devices.

For this reason it seems more appropriate to investigate the ferrite properties that are utilized direct in the devices in question, i.e. the Faraday rotation and associated losses in the case of Faraday-rotation devices and the isolation and insertion loss in the case of resonance devices. From such measurements, however, it is rather impracticable to deduce any intrinsic figure of merit of the material because of the complicated wave propagation mechanism in the partially filled test waveguide. This disadvantage may be eliminated by using relatively small ferrite cross-sections so that the wave propagation may be explained effectively by means of the first-order perturbation theory.

Unfortunately, these small ferrite cross-sections imply a very poor sensitivity in waveguide-transmission measurements. However, by using a tunable waveguide-cavity method rather than waveguide-transmission techniques, this drawback is eliminated. In addition to

this the tunable cavity technique offers the possibility of complete elimination of the end effects of the ferrite sample. This makes it possible to deduce the true propagation constants for the corresponding infinitely long ferrite-loaded waveguide.

Such a technique has been used by van Trier in Faraday rotation measurements at 24000 Mc/s (ref. 3), and the same method with some enlargements has been adopted in our effort to determine the applicability of some experimental ferrites to Faraday-rotation applications at frequencies of about 4500 Mc/s. This paper presents the experimental details of this work as well as the results for a few ferrites.

2. Theory of Experimental Technique

The experimental method employed here makes it possible to measure the real as well as the imaginary parts of the propagation constants of circularly polarized TE_{11} waves in a circular cylindrical waveguide containing a concentrically placed and longitudinally magnetized ferrite rod. From this it is possible to establish the ratio of Faraday rotation to insertion loss, which is assumed to be a figure of merit of the ferrite, provided the ratio of ferrite-to-waveguide cross-section is very small, and the biasing field is just sufficient to saturate the material. As previously shown by van Trier (ref. 3), it is possible to deduce also the real part of the dielectric constant and the saturation magnetization from the measured phase constants if the first-order perturbation theory can be applied. If however the dielectric constant is very high, its derivation becomes rather inaccurate, and other methods must be resorted to.

The tunable waveguide reaction-cavity is sketched in fig. 1. It consists of a circular cylindrical tube terminated by a short-circuiting movable plunger. The cover plate at the other end is provided with a coupling iris to the input waveguide. The ferrite rod is mounted in a teflon holder fastened in the coupling iris and extends through a concentric hole (waveguide beyond cut off) in the tuning plunger. If the cavity is empty, the TE_{11} resonance field may be regarded as the sum of two counter rotating circularly polarized fields. With the ferrite in place, this degeneracy is abolished, and the two circularly polarized fields become separated in cavity length. As is well known, the ferrite permeabilities for these fields are scalars given by:

$$\mu^{\pm} = \mu \mp k \qquad (1)$$

P 1705
23-2-58 E.S.
28-2-58 J.R.C.

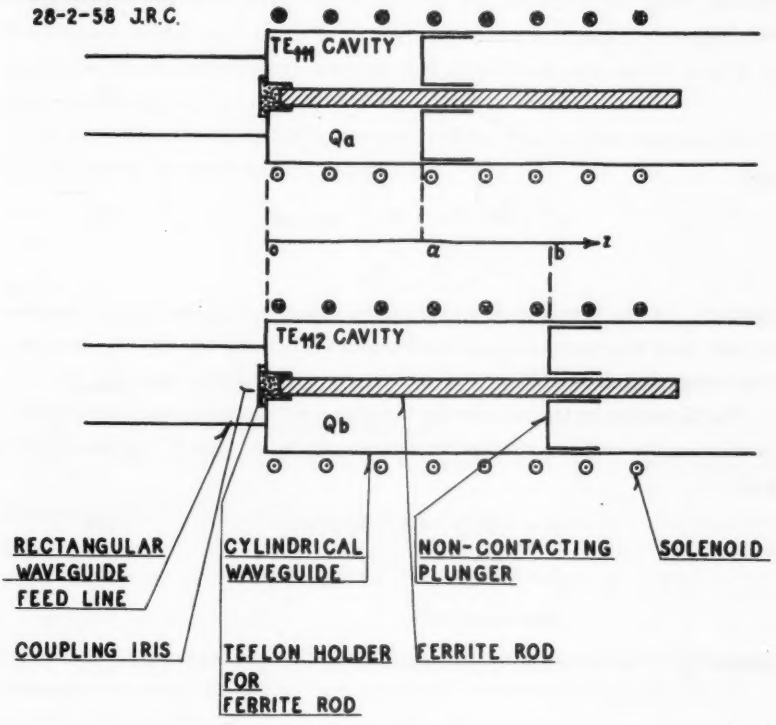


FIG.1

PRINCIPLE OF CAVITY METHOD.

where μ and k are the usual components of the tensor permeability. (+) refers to the clockwise sense of the circular polarization as seen along the direction of the magnetizing field. (-) indicates the opposite sense.

The propagation constants for these circularly polarized fields in the corresponding ferrite-loaded waveguide:

$$\Gamma^{\pm} = \alpha^{\pm} + j\beta^{\pm} \qquad (2)$$

are derived from the measured resonant lengths and unloaded Q's of the cavity with ferrite.

In order to eliminate the end effects of the ferrite rod and of the cavity, the cavity lengths and Q's are measured at both the half- and

the full-wave resonance. As may be shown, the propagation constants are then given by:

$$\beta^{\pm} = \frac{\pi}{b^{\pm} - a^{\pm}} \quad \text{Rad./cm} \tag{3}$$

and

$$\alpha^{\pm} = \frac{2\pi}{\lambda_o^2}\left[\frac{b^{\pm}}{Q_b^{\pm}} - \frac{a^{\pm}}{Q_a^{\pm}}\right] \quad \text{Ne/cm} \tag{4}$$

where λ_o is the free space wavelength, a and b are the cavity lengths at half- and full-wave resonance respectively, and Q_a and Q_b are the corresponding unloaded Q's of the cavity with ferrite (see fig. 1).

The Faraday rotation and the insertion attenuation per unit length of the ferrite rod are related to the quantities $\alpha^{\pm}$ and $\beta^{\pm}$ in the following way:

$$\Theta = 1/2\ (\beta^- - \beta^+) \text{ Rad/cm} \tag{5}$$

$$A \sim 1/2\ (\alpha^- + \alpha^+) - \alpha_o \quad \text{Ne/cm} \tag{6}$$

(for small α's)

where α_o is the attenuation constant of the empty waveguide.

3. Derivation of the Dielectric Constant, the Saturation Magnetization and the Isotropic Permeability in the Case of Zero Magnetization.

A van Trier (ref. 3) and Suhl and Walker (ref. 4) have derived the following expression for the phase constant $\beta^{\pm}$

$$\beta^{\pm} \cdot \left[\frac{r_o}{r_1}\right]^2 = \frac{K}{\beta_o}\left[\beta_o^2 \frac{\mu^{\pm} - 1}{\mu^{\pm} + 1} + \left(\frac{\omega}{c}\right)^2 \cdot \frac{\varepsilon - 1}{\varepsilon + 1}\right] + \beta_o \tag{7}$$

where K = dimensionless constant = 2, 1

r_1 and r_o are the ferrite and waveguide radii respectively

β_o is the phase constant of the empty waveguide

$\frac{\omega}{c}$ is the phase constant of free space

ε is the real part of the dielectric constant of the ferrite

$\mu^{\pm}$ are the real parts of the scalar permeabilities defined by eq. 1.

Eq. (7) rests upon the assumptions that the r.f. fields are homogeneous over the ferrite cross-section, and the field configuration in the waveguide is unpertubed except for a negligible region around

the ferrite. These conditions are only reasonably fulfilled for rod diameters less than 5 to 10 % of the free space wavelength, whereas practical Faraday rotators employ rod diameters around 17 - 20 % of this wavelength.

In the case of negligible magnetic losses, the scalar permeabilities are given by the well known relations:

$$\mu^{\pm} = 1 + \frac{\omega_m}{\omega_p \mp \omega} \tag{8}$$

where

$$\omega_m = -\gamma \mu_o M_o \qquad \gamma = \frac{e}{m} = -1{,}76 \cdot 10^{11}\ C/kg$$

$$\omega_p = -\gamma \mu_o H_{dc} \qquad \mu_o = 4\pi \cdot 10^{-7}\ H/m$$

M_o is the saturation magnetization.

H_{dc} is the magnetizing field as measured with the ferrite removed.

From (7) and (8) we find:

$$(\beta^- - \beta^+) \left[\frac{r_o}{r_1}\right]^2 = -K\beta_o \frac{\omega\, \omega_m}{(\omega_p + 1/2\ \omega_m)^2 - \omega^2} \tag{9}$$

ω_m (or M_o) may now be calculated from (9) by means of the difference between, the measured β's. $\mu^{\pm}$ are then calculated from (8) and introduced into (7), after which ε is found.

If the ferrite rod is demagnetized, μ^+ is equal to μ^-, and the cavity is again degenerate. The isotropic permeability μ_i may be calculated from (7) when ε is known, and the isotropic phase constant β_i i.e. the phase constant for the waveguide with the demagnetized ferrite rod, has been measured.

As eqs. (7) and (9) are valid only for infinitely small ferrite diameters, the following procedure has been employed: $\beta^{\pm}$ were measured for a series of ferrite rod diameters, and $\beta^{\pm} \cdot \left[r_o/r_1\right]^2$ were plotted against $\left[r_1/r_o\right]^2$. Extrapolation of these curves to $\left[r_1/r_o\right]^2 = 0$ provided us with the limiting values required in eq. (7) and (9).

It was hoped, that - in the case of small losses - this procedure might be extended to include a determination of the imaginary parts of the dielectric constant and the permeabilities by means of the imagninary counterpart of eq. (7), and the measured attenuation constants. However, for reasons to be explained later, it was not possible to measure these with sufficient accuracy to permit the extrapolation mentioned above.

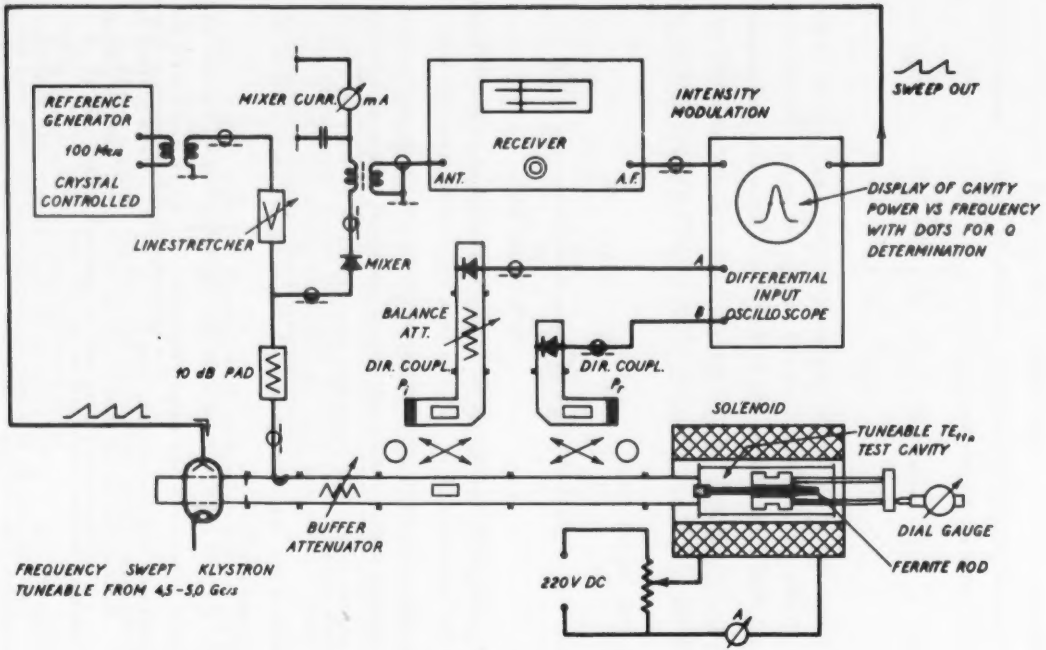


FIG. 2

EXPERIMENTAL ARRANGEMENT FOR THE DETERMINATION OF THE PROPAGATION CONSTANT OF A CIRCULAR WAVEGUIDE CONTAINING A SLENDER MAGNETIZED FERRITE ROD.

P.1705.
26.2.58.

4. Experimental Procedure.

The measuring circuit is shown in fig. 2. A frequency-swept klystron feeds the test cavity through a measuring line containing directional couplers for the incident and reflected powers. The output voltages from the square-law crystal detectors terminating the couplers are fed to an oscilloscope with differential input. By proper adjustment of the balance attenuator, a display of the power dissipated in the cavity versus the frequency may be obtained.

For the determination of the phase constants, the cavity resonances are tuned to the same frequency (the same position on the oscilloscope trace), and the corresponding cavity lengths are measured.

For the measurement of Q, a heterodyne technique has been employed, A 100 Mc/s crystal-controlled signal is mixed with the microwave signal, which is swept around 4600 Mc/s. In the mixer output the frequency component, which is equal to the instantaneous deviation from 4600 Mc/s of the microwave frequency, is detected by a conventional radio receiver, the a.f. output of which intensity-modulates the oscilloscope. When the receiver is tuned to frequency f Mc/s, two bright spots corresponding to the microwave frequencies $4600 \pm f$ Mc/s appear on the trace. By proper adjustment of f, these spots may be places in the half power points of the resonance curve. The loaded Q is then equal to

$$Q_L = \frac{4600}{2f} \qquad (10)$$

When using this technique, the following must be considered: The klystron of course is tuned to maximum power at the measuring frequency. Hence, if the cavity Q is low, the klystron power will be noticeably lower at the frequencies corresponding to the half-power points, and the correct position of the dots is therefore somewhat below the middle of the resonance curve. There are several ways of eliminating this difficulty. The use of a low-Q transmission cavity (not shown in fig. 2) inserted between the klystron and the measuring line proved to be the best. By adjusting the coupling and the Q of this cavity, it was possible to obtain an approximately flat power response over the entire klystron mode. The insertion loss of this arrangement was about 10 dB's.

In a few cases where the bandwidth of the ferrite-loaded test cavity was even larger than the frequency band of the klystron mode, the directional couplers were replaced by a slotted line, and the Q's were

derived from the measurements of the standing-wave ratio around resonance.

The relations between the loaded and the unloaded Q's of the test cavity are:

$$Q_u = Q_L \quad (1 + 1/d) \tag{11}$$

if the cavity is under-coupled, and

$$Q_u = Q_L \quad (1 + d) \tag{12}$$

if it is over-coupled; where d is the voltage standing-wave ratio at resonance.

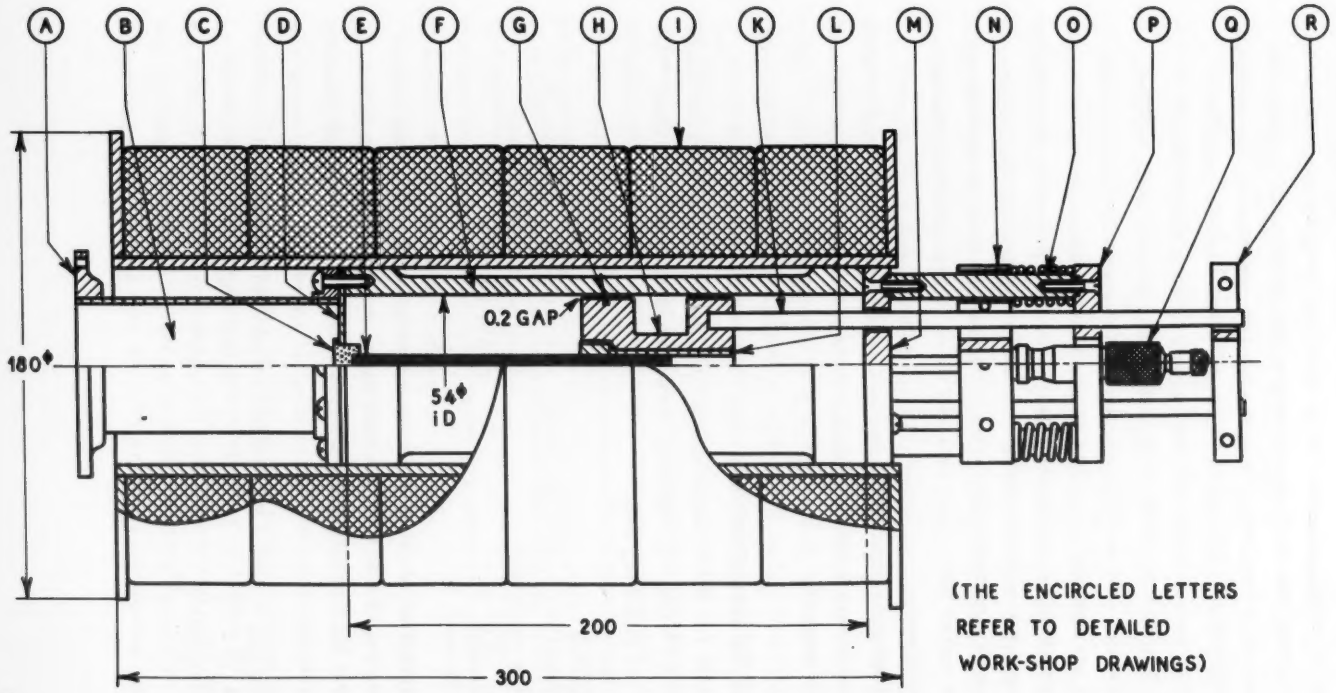
The question of under- or over- coupling is conveniently settled once for all by making sure that the cavity without ferrite is slightly under-coupled. This may be checked by an examination of the standing-wave behavior around resonance by means of a slotted line section. Thus if a particular standing-wave minimum corresponding to a completely detuned cavity first moves away from and then returns to its initial position, when the cavity is tuned gradually to resonance, the coupling is less than critical. On the other hand if it shifts to a new position one quarter of a wavelength away from the initial position during the tuning procedure, the coupling is overcritical. When the empty cavity is under-coupled, we know beforehand that the ferrite-loaded cavity will be the still more under-coupled because of the additional ferrite losses.

The voltage standing-wave ratio at resonance may be measured direct by means of a slotted line section in front of the test cavity, or it may be calculated from the power-reflection coefficient Γ^2, as measured by means of the directional couplers in fig. 2.

$$\Gamma^2 = \frac{P_r}{P_i} = \frac{V_r}{V_i} \tag{13}$$

where P_r and P_i are the reflected and incident powers on the measuring line, and V_r and V_i are the output voltages from the square-law crystal detectors in the corresponding directional couplers. V_r may be read in arbitrary units on the oscilloscope by placing a short circuit across the input terminal corresponding to V_i and vice versa for V_i. The standing-wave ratio is then obtained from the relation:

$$d = \frac{1 + \Gamma}{1 - \Gamma} \quad . \tag{14}$$



(THE ENCIRCLED LETTERS REFER TO DETAILED WORK-SHOP DRAWINGS)

FIG. 3
1:2 CUT-AWAY VIEW SHOWING ASSEMBLY OF TEST CAVITY AND MAGNET.

P. 1705
27. 2. 58.

To obtain very precise measurements, the Q's must be corrected for the effect of resistive losses in the coupling between the measuring line and the cavity, the finite directivity of the directional couplers as well as the effect of deviation from square-law response of the crystal detectors. As the errors originating from these sources usually appeared not to exceed a few per cent of any measurement result contained in this report, such corrections have largely been omitted.

On an average, the accuracy of the procedure outlined above was better than 5 per cent for α^{+}_{-}. The marked temperature dependence of the ferrite losses to be mentioned later gave rise, however, to considerable differences (up to 20 per cent) between the corresponding values of α^{+} in successive measurement series. The accuracy of the difference $(\beta^{-} - \beta^{+})$ was better than 1 per cent and those of the individual values of β^{+}_{-} were still better.

Special problems concerning the test cavity and the solenoid magnet will be treated in Appendix I. Fig. 3. shows a cut-away view of the cavity and the magnet.

5. Results of the Measurements.

The results for three experimental low magnetization ferrites made by A/S FERROPERM, DENMARK, are presented in this section. The ferrites had the following data:

Sample I

Composition in mol per cents:	16 Cr_2O_3-49 MgO-35Fe_2O_3
Firing conditions	4 hours at 1350°C in air
$\mu_o M_o$ (20° C)	0.056 Wb/m^2
Curie point T_c	145°C

The composition of this ferrite is the same as that originally found by P. E. Ljung in SWEDEN in his search for a material with a high figure of merit for Faraday-rotation applications at frequencies around 3000 Mc/s (ref. 5)

Sample II is also a magnesium chromium ferrite with

$\mu_o M_o$ (20°C)	0.076 Wb/m^2
Curie point T_c	390°C

Sample III is a magnesium aluminium ferrite with

$\mu_o M_o$ (20°C)	0.105 Wb/m^2
Curie point T_c	225°C

Graphs I, II and III show the alterations $\Delta\beta^{\pm}_{m}$ of the phase constant due to the magnetizing field. $\Delta\beta^{\pm}_{m}$ is defined by:

$$\Delta\beta^{\pm}_{m} = \beta^{\pm} - \beta_i \qquad (15)$$

where β_i is the phase constant of the waveguide with the ferrite rod demagnetized. $\Delta\beta^{-}_{m}$ is rather independent of the magnetizing field above saturation, whereas $\Delta\beta^{+}_{m}$ increases with the field as it approaches gyromagnetic resonance. Unfortunately, the magnet did not permit of measurements around resonance.

Graphs IV, V and VI show the corresponding attenuation constants $\alpha^{\pm}$ for waveguide plus ferrite. The insertion values for the ferrites are found by subtracting α_o, the attenuation constant of the empty waveguide, from $\alpha^{\pm}$ (acutally, this is only true of such small values of α as those reported here). α_o is indicated in each graph by the line marked $r_1 = 0$ (α_o has a higher value in graph IV than in graph V and VI. The reason for this is that a different cavity was used at that time). Here again α^{-} is fairly constant above saturation, whereas α^{+} increases with the field. Sample I has by far the lowest losses of the three ferrites. For negative circular polarization the combined losses of this ferrite and of the waveguide are hardly distinguishable from the losses of the waveguide itself. This indicates that not only the magnetic, but also the dielectric losses are extremely small. The small magnetic losses are partly due to the fact that the ferrite operates far below gyromagnetic resonance because of the low saturation magnetization.

The difference between the dotted and the solid curves in graph VI gives a typical picture of the poor repeatability in successive series of Q measurements. This was investigated separately, and the uncertainty was found to originate in the large temperature coefficients of the ferrite losses. Graph VII shows the variation of Q with the cavity temperature as measured at the plunger for one of the ferrite rods. (Sample III, diameter 9 mm). The increase of Q with temperature is most pronounced for positive circular polarization in high magnetizing fields. This is not surprising, considering that the saturation magnetization decreases with

increasing temperature, and the magnetic resonance therefore is shifted towards higher fields. On the other hand, this explanation does not account for the fact that the temperature coefficient seems to increase again with the magnitude of the field for negative circular polarization.

Graph VIII shows the ratio of Faraday rotation to insertion loss for the smallest rod diameters of the three ferrite samples. The maximum value of this ratio is taken as the figure of merit of the ferrite. Sample I has by far the largest figure of merit of the three materials. It is felt, however, that the efficiency of this material i.e. the Faraday rotation per unit volume, is too low for practical applications at this frequency. Samples II and III have approximately the same figures of merit, but the high saturation magnetization of III causes the ratio to drop faster with increasing field. Sample II requires a relatively high field for saturation and shows rather marked low-field losses.

Graphs IX, X and XI show the normalized phase constants $\beta^{\pm} \cdot \left[r_o/r_1\right]^2$ versus the normalized ferrite rod cross-sections $\left[r_1/r_o\right]^2$ for the three ferrites. These curves are extrapolated to $\left[r_1/r_o\right]^2 = 0$ for the determination of the dielectric constant and the permeabilities as mentioned in section 3. These curves must be horizontal within the diameter range to which the first-order perturbation solution-, eq. (7), applies. This range is particularly small for sample III, for which a noticeable deviation from the theory appears for a ferrite cross-section of even one per cent of the waveguide cross-section. This is consistent with the high value of the dielectric constant found for this ferrite.

The intrinsic parameters of the ferrites as calculated on the basis of the graphs IX, X and XI and by means of the theory in sec. 3 are presented in table I. The dielectric constants are actually calculated from the quantity $(\varepsilon - 1)/(\varepsilon + 1)$, which may be determined from the above mentioned graphs. The large value of ε for sample III is therefore rather uncertain. The low value: $\varepsilon \sim 6,7$ for sample I presumerably is due to the high porosity of the chromium ferrites. (The specific gravity is about 3.5 gr. per cm^3 for sample I). Using other methods, P. E. Ljung in Sweden has measured values of ε around 6.4 for a similar material.*)

---

*) Private communication.

Ferrite	$\mu_o M_o$ Wb/m^2		ε	μ_i
	calculated from microwave measurements.	measured by ballistic fluxmeter	relative dielectric constant	isotropic permeability (H=0)
Sample I	0.059	0.056	6.7	0.94
Sample II	0.092	0.075	10.6	0.86
Sample III	0.122	0.105	~25	0.77

Table I

Intrinsic parameters for the three ferrites.

Discussion of the Figure of Merit of the Ferrites.

If a gyromagnetic resonance line of the Lorentzian type is assumed as is usual, the complex scalar permeabilities for circular polarization $\mu^{\pm}$ may be expressed by:

$$\mu^{\pm} = 1 + \frac{\omega_m}{\omega_p \mp \omega + j\Delta\omega} \qquad (16)$$

where ω_m and ω_p are defined in eq. 8 and $\Delta\omega = -1/2\gamma\mu_o \Delta H$. ΔH is the gyromagnetic resonance linewidth.

If in addition the dielectric losses can be neglected as compared to the magnetic losses, it is possible, as shown by B. Lax (ref. 2), to express the figure of merit of the ferrite as:

$$F = (\Theta/A)_{max} = \frac{\omega}{\Delta\omega} \qquad \text{Rad./Ne.} \qquad (17)$$

when the magnetic field is small compared to that required for resonance, and the ratio of ferrite-to-waveguide cross-section is small.

In order to compare our results with this theoretical figure of merit, the resonance linewidths of small spheres of the ferrites were measured. *) The results of these measurements as well as the calculated and experimentally determined figures of merits are presented in table II.

	ΔH Oersteds	ΔH A. T. /m	F calculated from eq. 17	F measured Graph VIII
Sample I	362	$2.88.10^4$	9.1	520
Sample II	952	$7.57.10^4$	3.47	145
Sample III	423	$3.67.10^4$	7.15	135

Table II Comparison of experimental and theoretical figures of merit of the three ferrites at 4600 Mc/s .

*) These measurements will be described in a later report. The method is explained in ref. 6.

As will be seen, the theoretical figures of merits are far lower than the measured ones, and the correlation between the measured values of ΔH and F is very poor. We have not as yet been able to explain this considerable disagreement quantitatively, but in favour of our results, it may be added, that the actual resonance lines are unsymmetrical in that the ferrite losses drop faster on the low-field side of resonance than predicted by (16). The agreement might possibly have been better for single-crystal ferrites, for which - according to B. Lax (ref. 2) - the assumption of a Lorentzian line shape appears to be more realistic.

In view of this we feel that a better understanding of the loss mechanism in polycrystalline microwave ferrites is required before reasonably true figures of merit can be deduced from the knowledge of a few or a single ferrite parameter such as ΔH.

E. V. Sørensen

References.

1. C.L. Hogan:
The Low-Frequency Problem in the Design of Microwave Gyrators and Associated Elements.
Proceedings of the Symposium on Electromagnetic Wave Theory.
University of Michigan, June 20-25 1955, p. 494.

2. B. Lax:
Frequency and Loss Characteristics of Microwave Ferrite Devices.
Proc. IRE vol. 49, Oct. 1956, p. 1368.

3. A.A. Th. M. van Trier:
Guided Electromagnetic Waves in Anisotropic Media.
Appl. Sci. Res. B. III, 1953, p. 344.

4. H. Suhl and L.R. Walker:
Topics in Guided Wave Propagation through Gyromagnetic Media.
B.S.T.J. vol. XXXIII, Sept. 1954, p. 1133.

5. B. Josephson and P.E. Ljung:
Microwave Ferrites.
L.M. Ericsson Techniques No. 1, 1958.

6. P. Christensen, M. Grønlund, E.V. Sørensen
Note on Measurements of the Gyromagnetic Resonance Linewidth of Microwave Ferrites.
Report P. 1760, 15th July 1959.
Microwave Laboratory, A.T.S. Copenhagen, Denmark.

APPENDIX I

Special Problems regarding Test Cavity and the Solenoid Magnet.

The chief requirement to the test cavity shown in fig. 3 is that it must be degenerate for mutually orthogonal TE_{11} modes, i.e. it must possess the highest degree of rotational symmetry. If this condition is insufficiently fulfilled, a resonance splitting will be observed, even without ferrite in the cavity, and this makes it impossible to determine the β's. During the initial part of this work a cavity made from an ordinary drawn brass tube was employed. For the above- mentioned reason it had to be replaced by a thick-walled cavity turned out of a solid brass rod, which was annealed in advance in order to reduce the internal stresses. Other requirements are a high and reproduceable Q, which was obtained by means of silverplating and through the use of a well designed shortcircuiting plunger of the non-contacting type. The plunger is guided by three small nylon pins seated along the circumference. During the first measurements it was provided with an interchangeable brass guide sleeve for the ferrite rod. However, this sleeve having been found to give rise to some spread in the Q measurements, it was later replaced by a teflon sleeve.

The unloaded Q's and resonant lengths of the empty cavity at 4600 Mc/s were

$Q_a = 13210$
$a = 4,54$ cm half wave resonance
$Q_b = 18100$
$b = 9,14$ cm full wave resonance

With these values, the attenuation constant as calculated from eq (4) for the corresponding circular waveguide without ferrite becomes

$$\alpha_o = 2,41 \cdot 10^{-5} \text{ Ne/cm} .$$

The theoretical value calculated for the same waveguide with perfect silverplating was found to be:

$$\alpha_o = 2,22 \cdot 10^{-5} \text{ Ne/cm} .$$

In order to keep the temperature of the ferrites as near to room temperature as possible, an air stream was passed through the tuneable cavity. The air was dried in a silica gel cell before the injection to keep the moisture content of the hygroscopic ferrites as low as possible.

The chief requirement to the magnetizing field is that it must be constant along the axis of the ferrite rod in the interval b-a in fig. 1. Outside this interval some deviations may be tolerated, as their effect is eliminated in the measuring procedure. This part of the ferrite rod should therefore be placed in the middle section of the solenoid magnet. In order to improve the constancy of the field, the magnet coils in this section may be shunted by resistors as shown i fig. 4. Another method having an additional advantage with a view to better cooling of the magnet, is to space the coils somewhat.

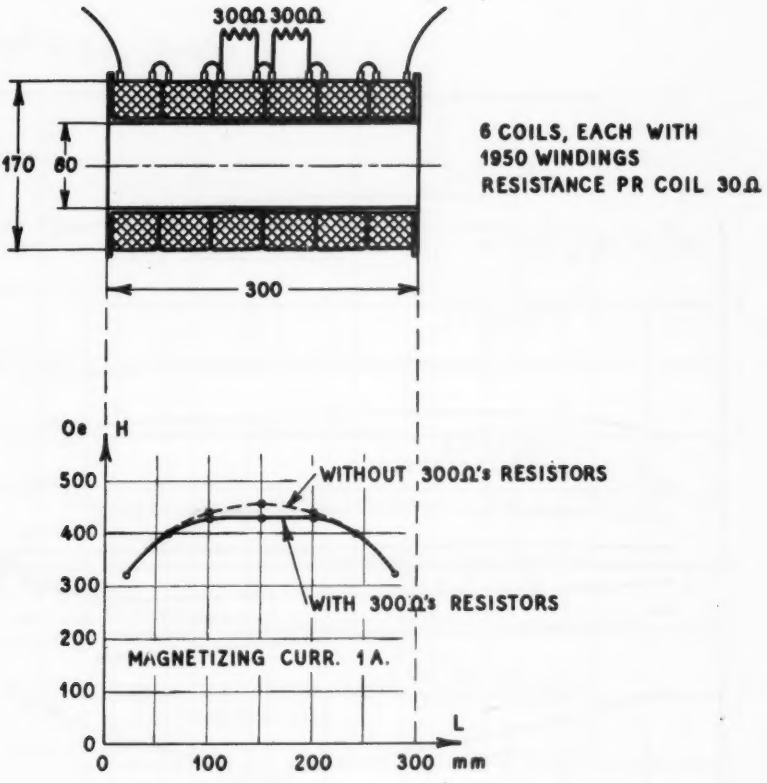
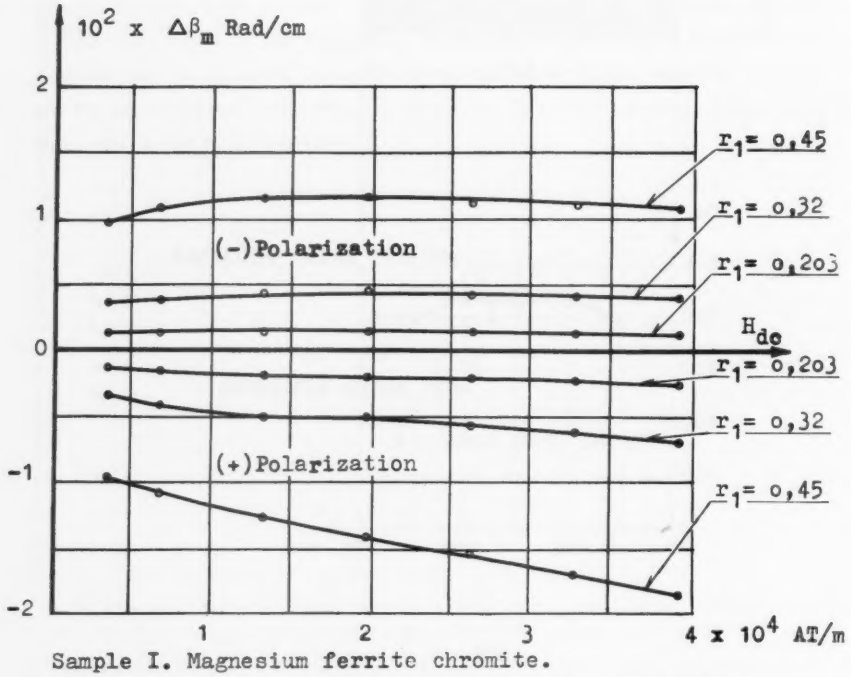


FIG. 4

AXIAL VARIATION OF SOLENOID MAGNETIC FIELD FOR 1A. MAGNETIZING CURRENT.

FLAT CURVE OBTAINED BY MEANS OF SHUNTING RESISTORS.

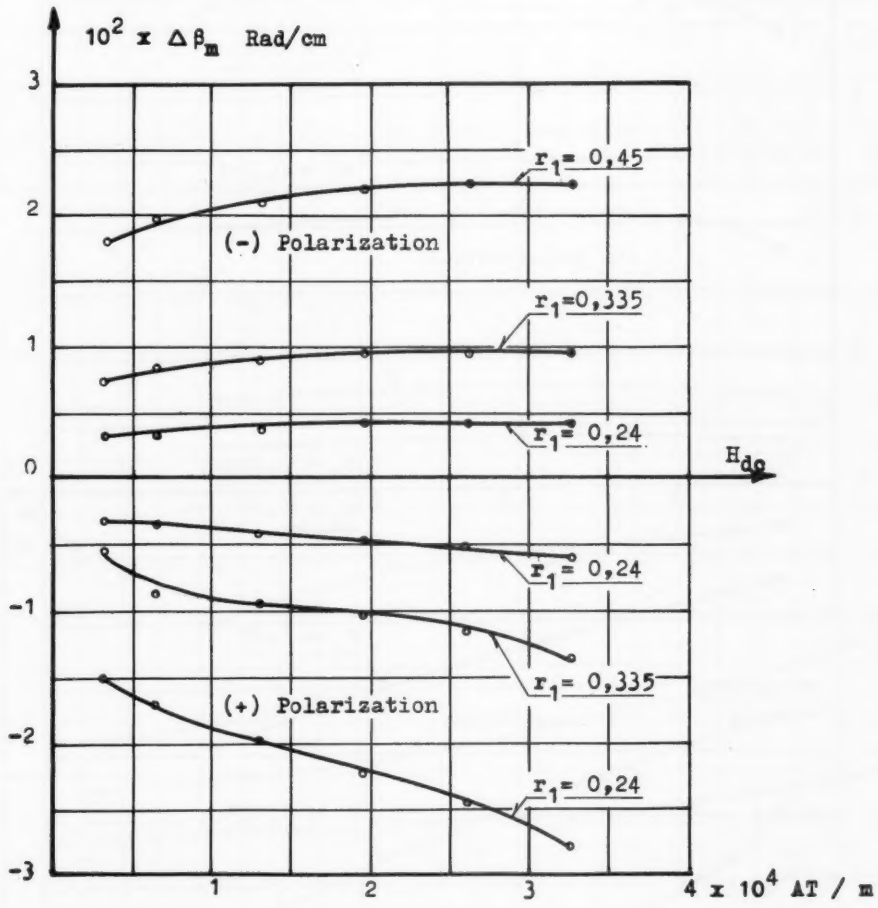
P. 1705
3. 3. 58.



Sample I. Magnesium ferrite chromite.
Perturbations of phase constants due to magnetizing field for various ferrite radii.
Ferrite radius $r_1$cm.TE_{11}- Waveguide radius r_o= 2,7 cm.
Frequency f = 4600 MC/s

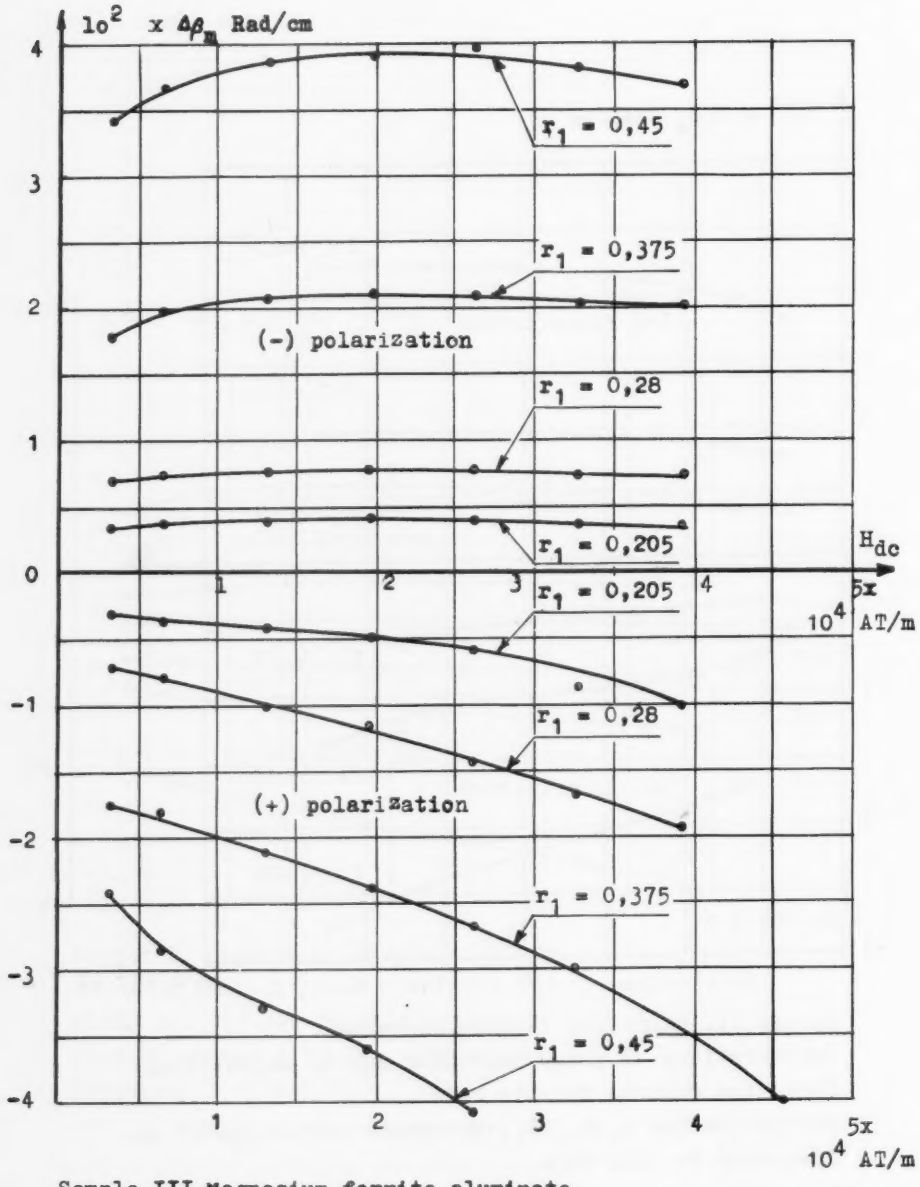
Graph I

P. 1705



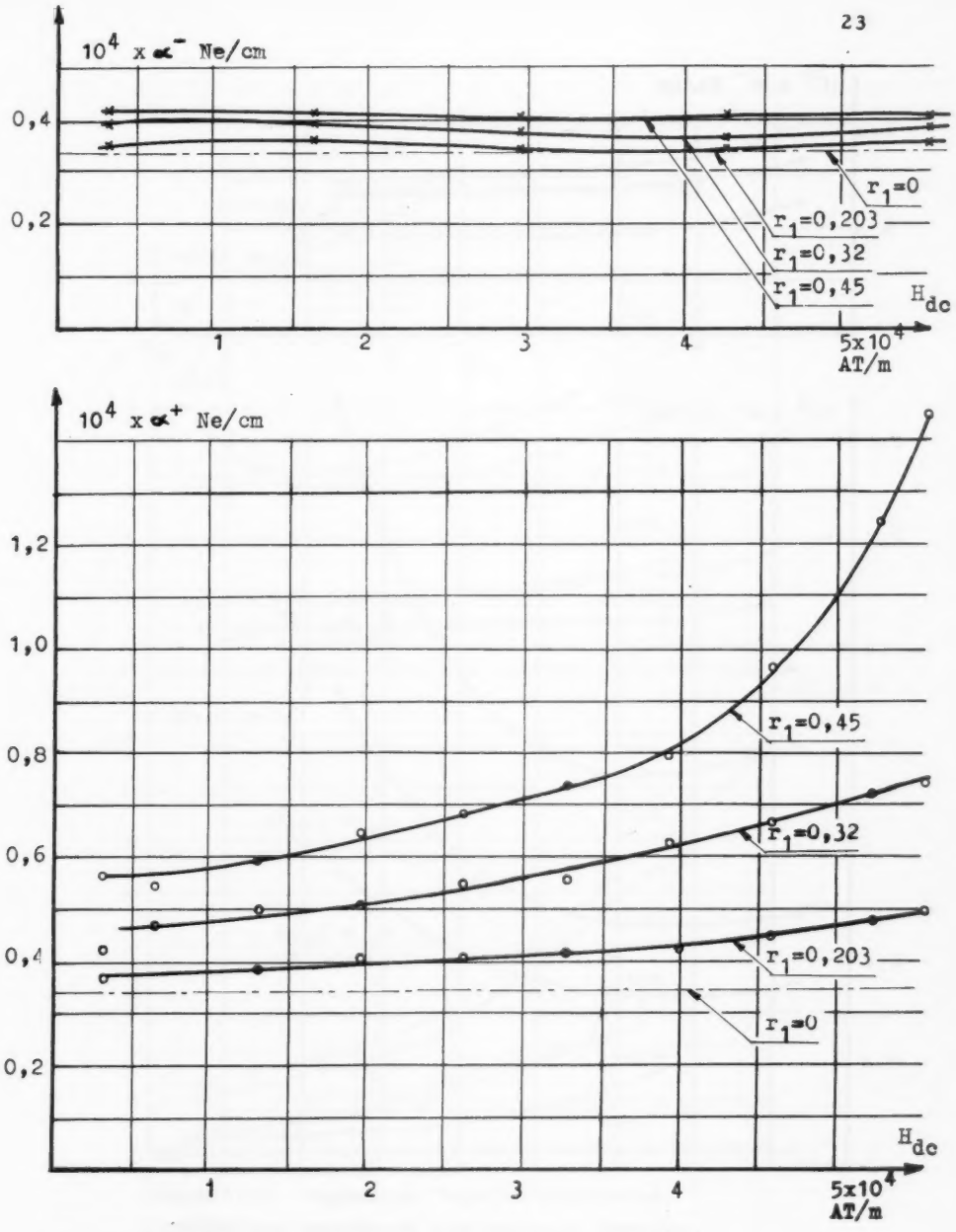
Sample II. Magnesium ferrite chromite.
Perturbations of phase constants due to magnatizing field for various ferrite radii.
Ferrite radius $r_1$cm. TE_{11}-Waveguide radius r_0=2,7 cm.
Frequency f= 4600 MC/s

Graph II



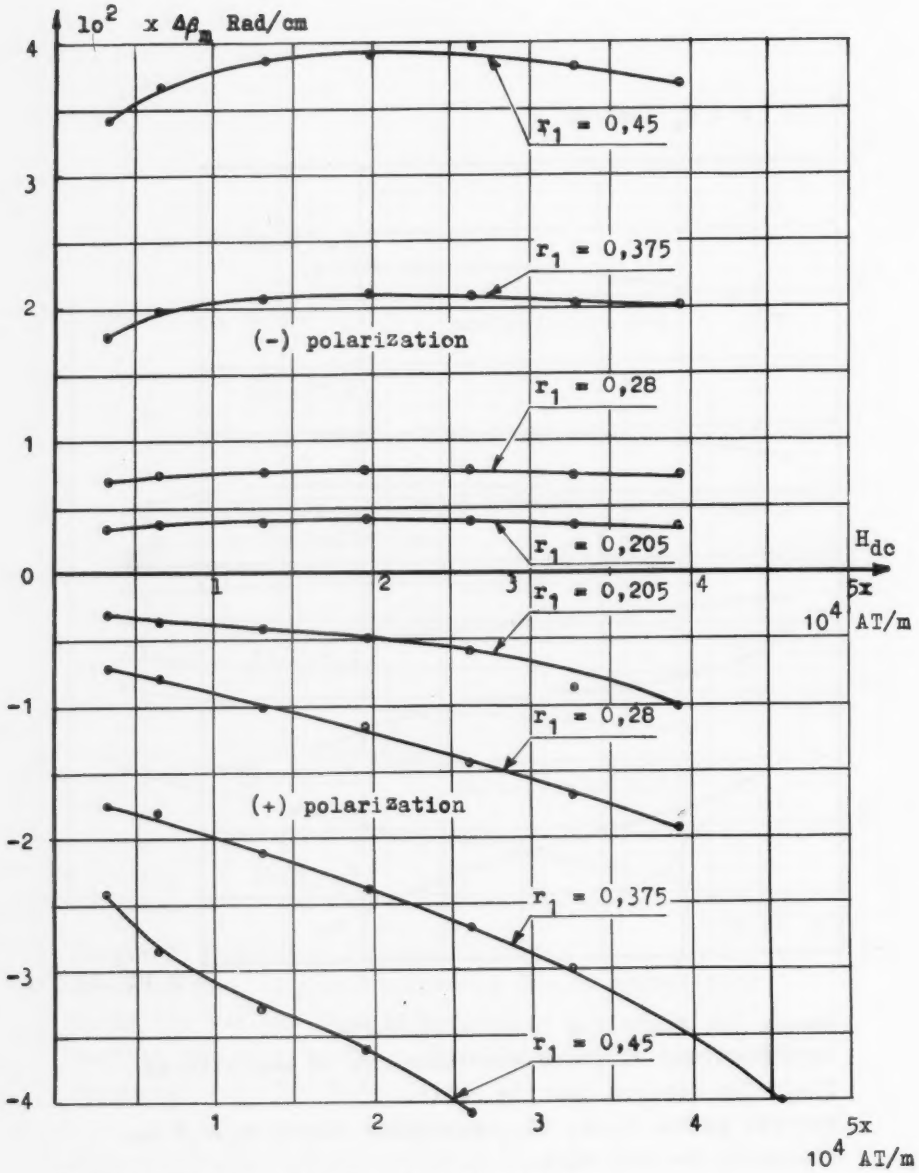
Sample III Magnesium ferrite aluminate.
Perturbations of phase constants due to magnetizing field for various ferrite radii.
Ferrite radius r_1 cm, TE_{11}- waveguide radius r_o 2,7 cm,
Frequency f = 4600 MC/s

Graph III. P 1705



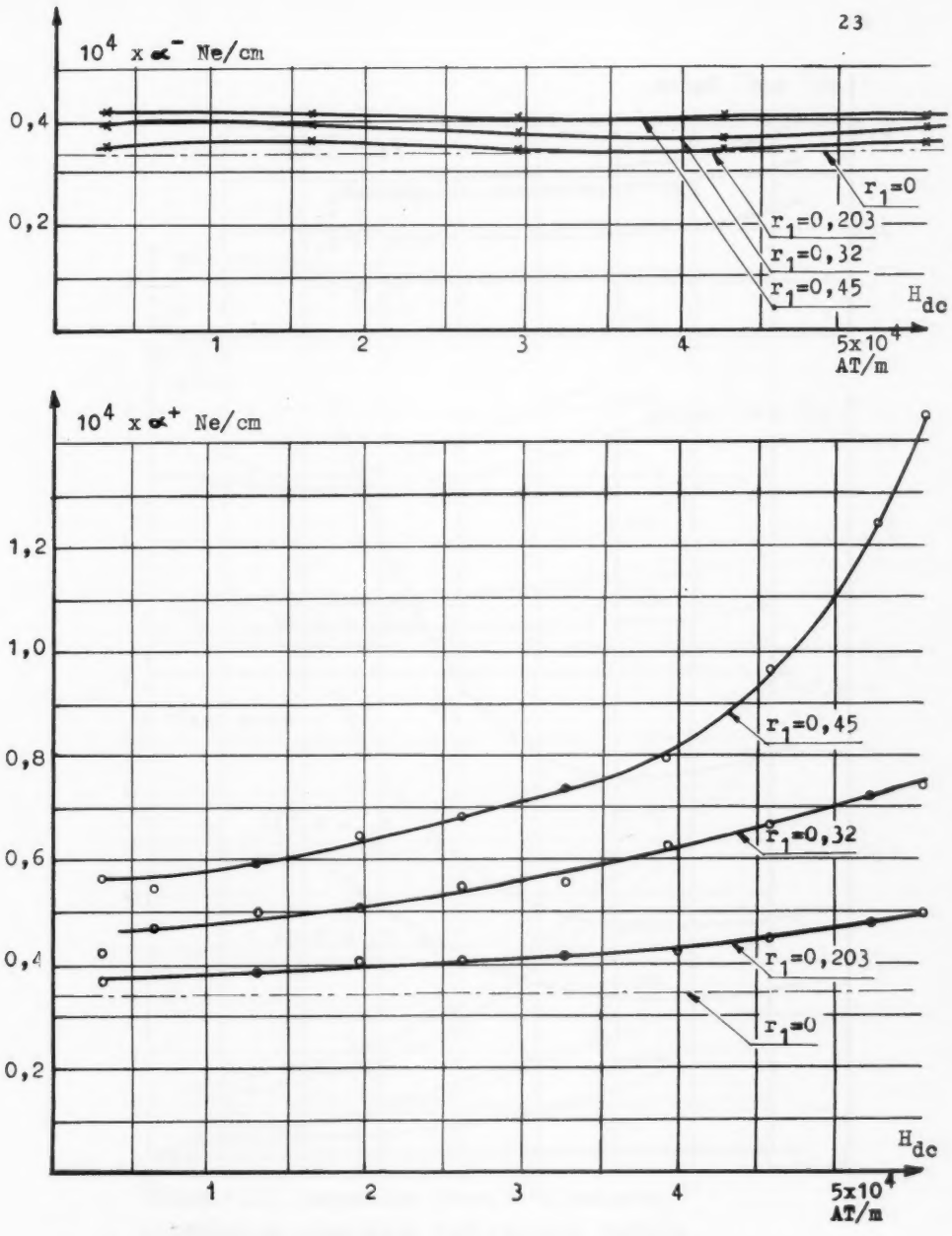
Sample I Magnesium ferrite chromite.
Attenuation constants for various ferrite radii vs magnetizing field.
Ferrite radius r_1 cm. TE_{11}-waveguide radius r_o = 2,7 cm
Frequency 4600 MC/s

Graph IV. P 1705



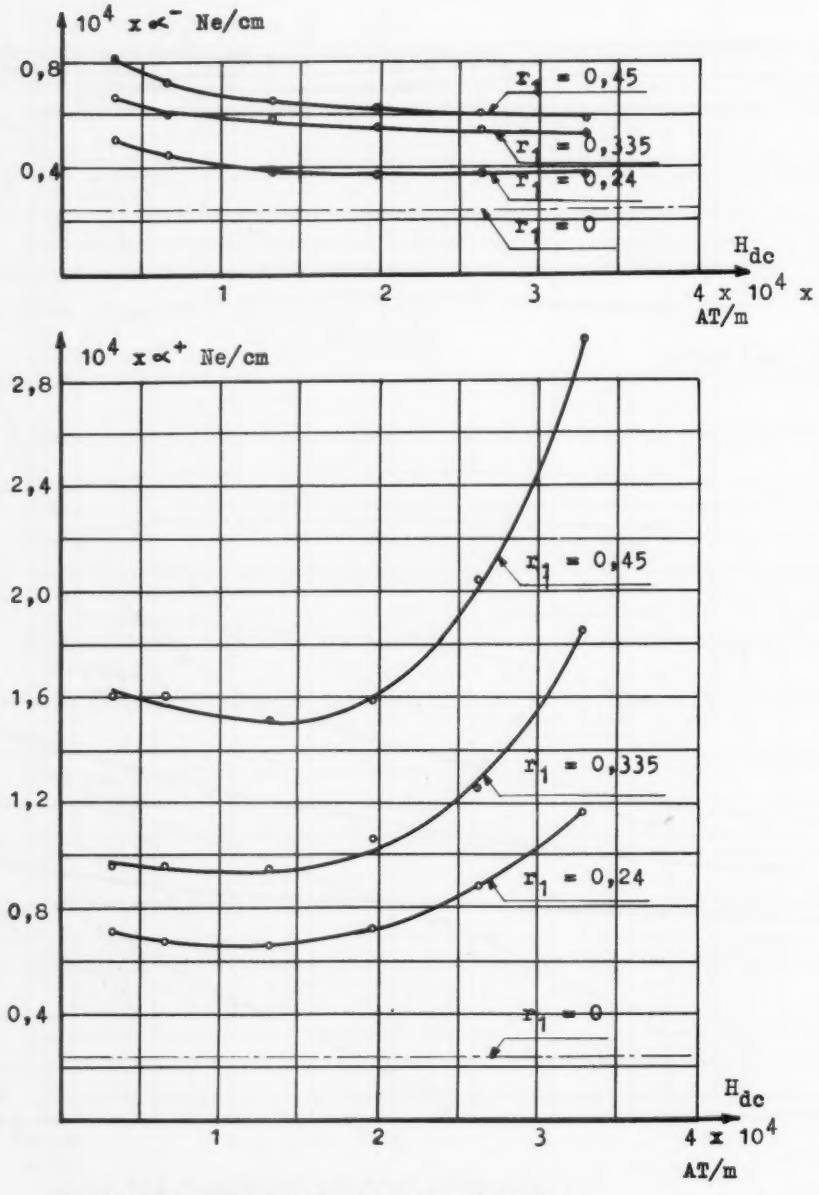
Sample III Magnesium ferrite aluminate.
Perturbations of phase constants due to magnetizing field for various ferrite radii.
Ferrite radius r_1 cm, TE_{11}- waveguide radius r_o 2,7 cm,
Frequency f = 4600 MC/s

Graph III. P 1705



Sample I Magnesium ferrite chromite.
Attenuation constants for various ferrite radii vs magnetizing field.
Ferrite radius r_1 cm. TE_{11} waveguide radius r_o = 2,7 cm
Frequency 4600 MC/s

Graph IV. P 1705



Sample II. Magnesium ferrite chromite.

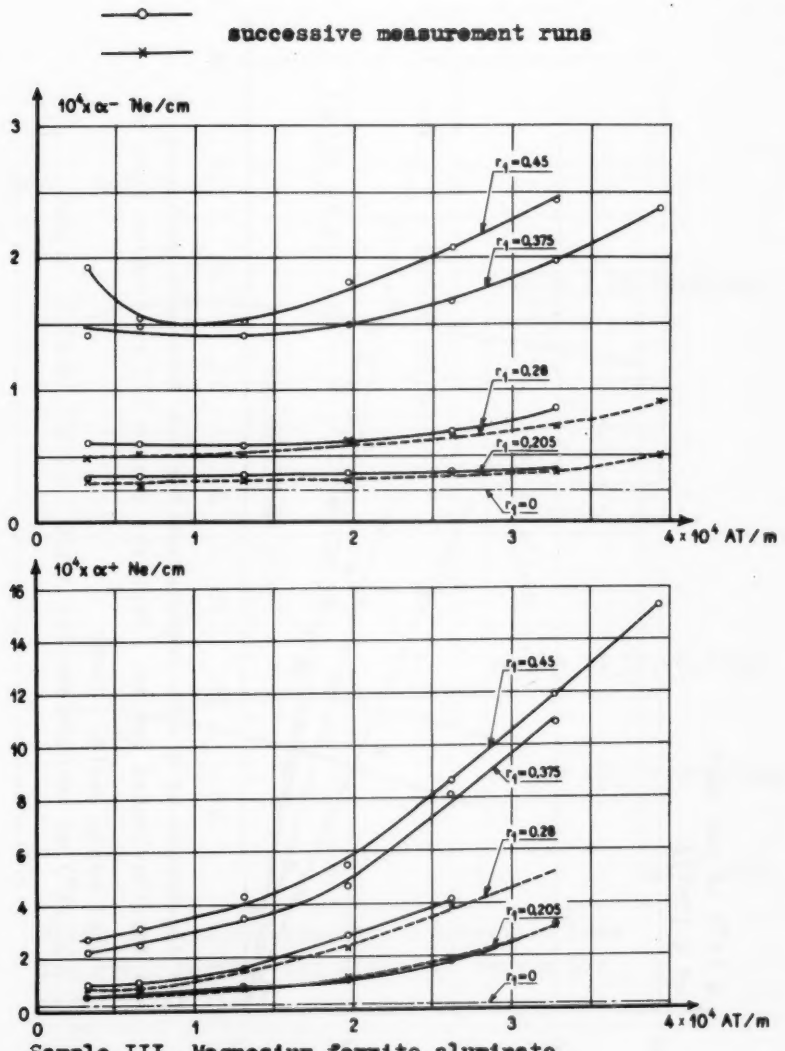
Attenuation constants for various ferrite radii vs magnetizing field.

Ferrite radius r_1 cm. TE_{11}-waveguide radius r_o = 2,7 cm

Frequency 4600 MC/s

Graph V

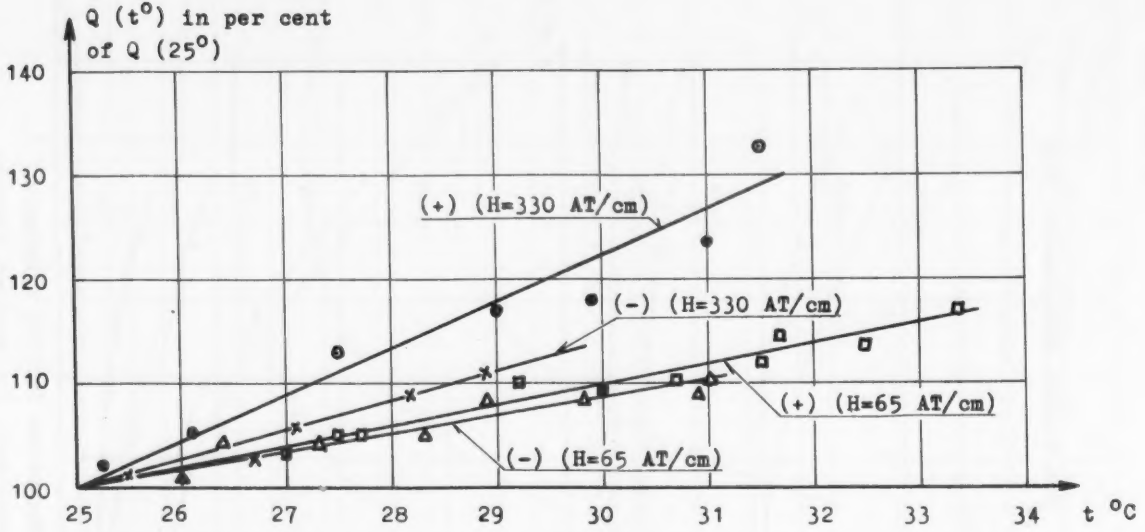
P 1705



Sample III. Magnesium ferrite aluminate.
Attenuation constants for various ferrite radii v.s. magnetizing field.
Ferrite radius r_1 cm. TE_{11}-Waveguide radius r_0=2.7 cm.
Frequency 4600 Mc/s.

Graph VI

P 1705

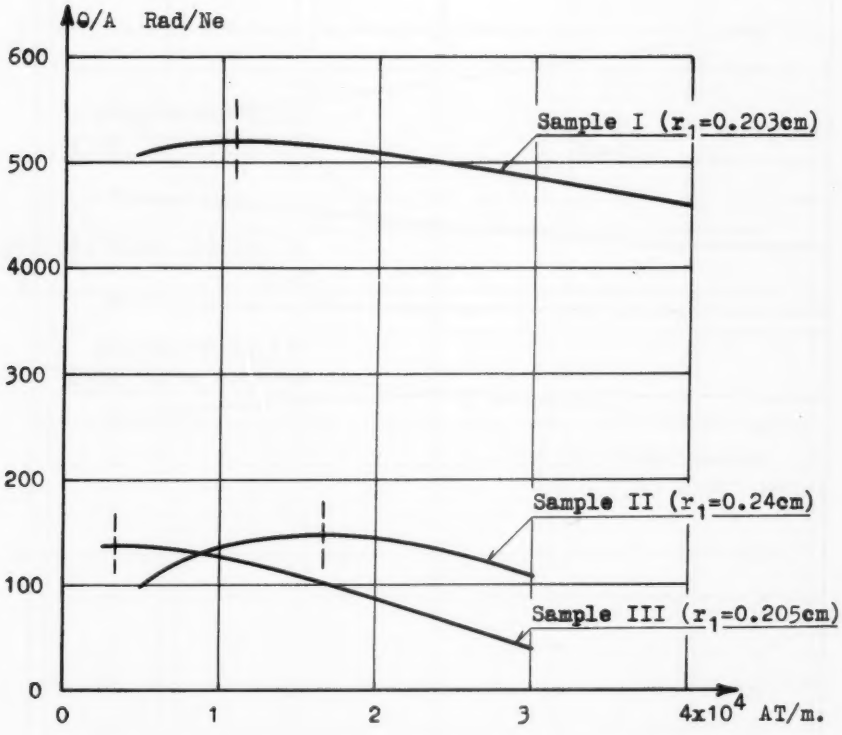


GRAPH VII

The dependence of Q with temperature for the full-wave resonance in the ferrite-loaded cavity. Ferrite: Sample III rod-radius 0.45 cm.

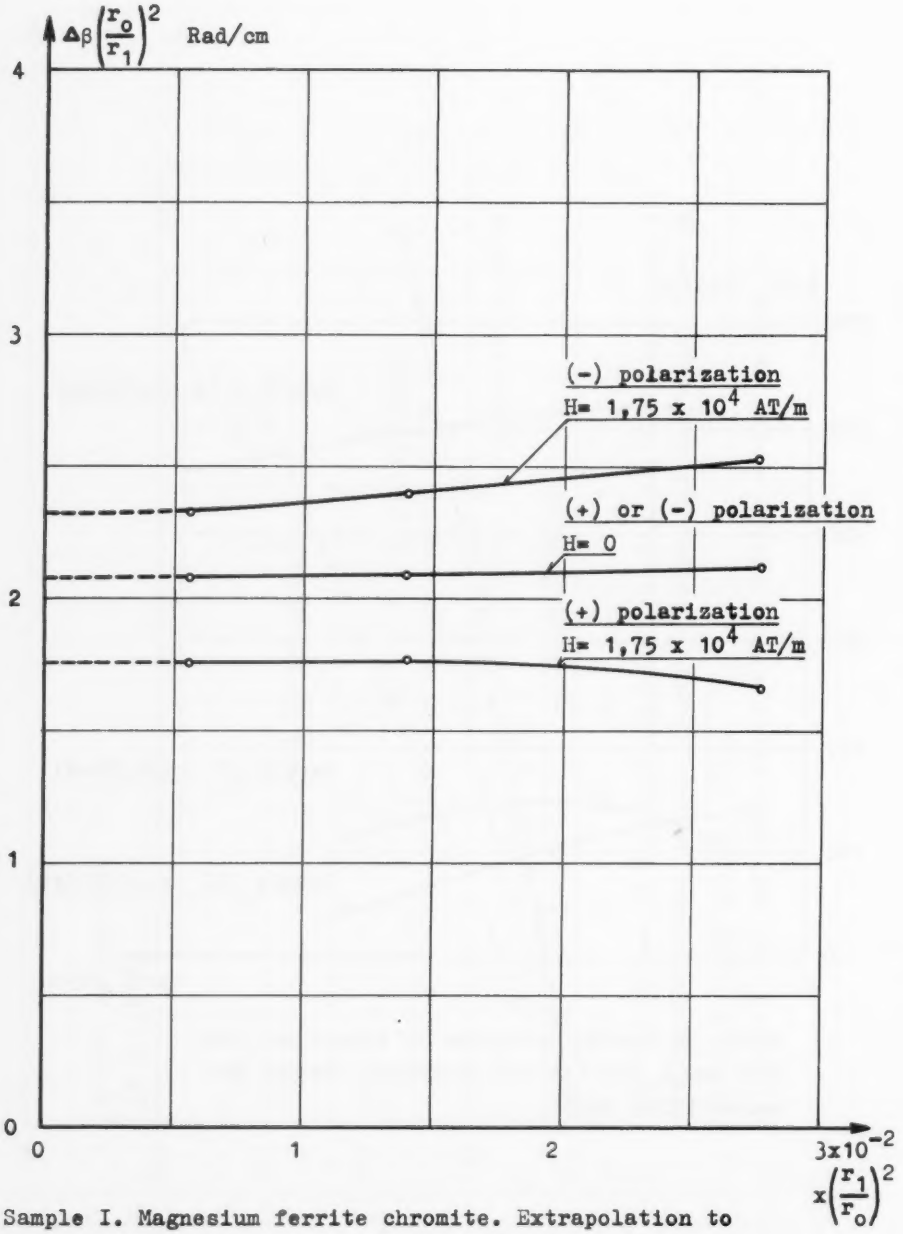
Q of empty cavity 18000

Q (25°) of cavity+ferrite: ⊙500 ×2030 □2025 △3540



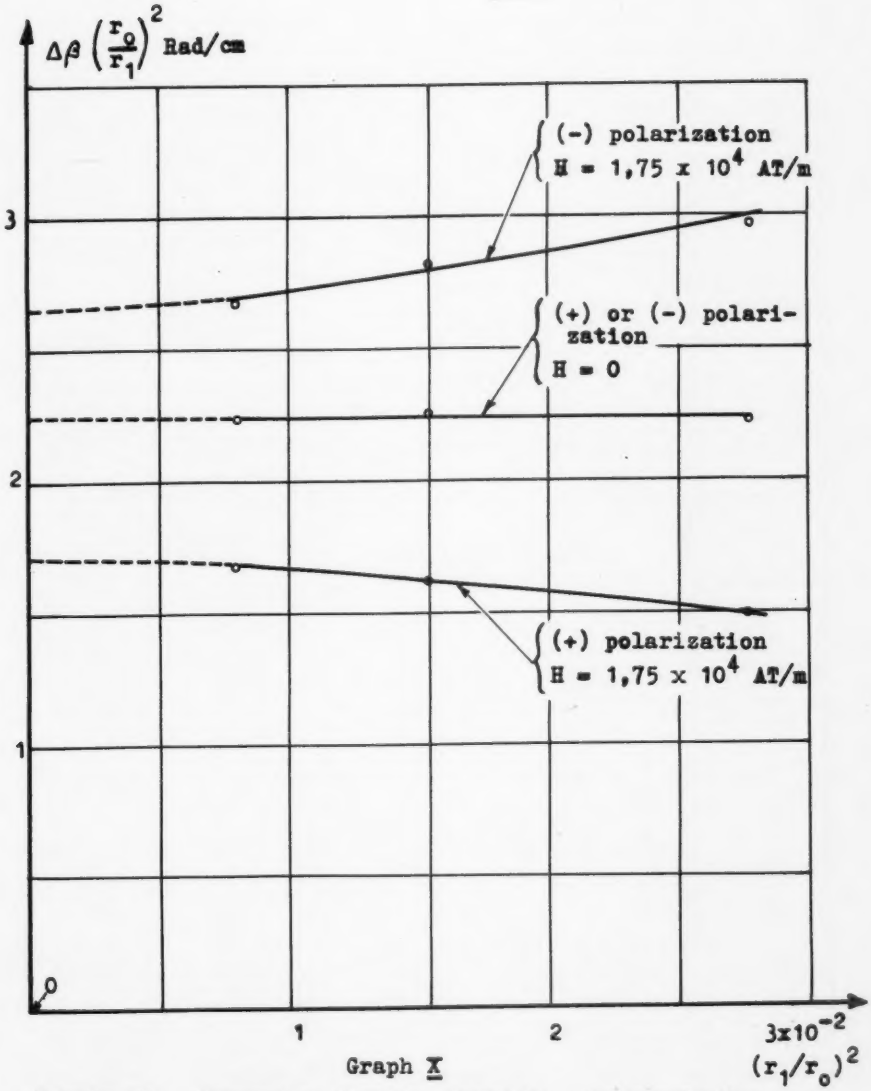
Ratio of Faraday rotation to insertion loss for small ferrite-rod diameters versus the magnetizing field.

GRAPH VIII



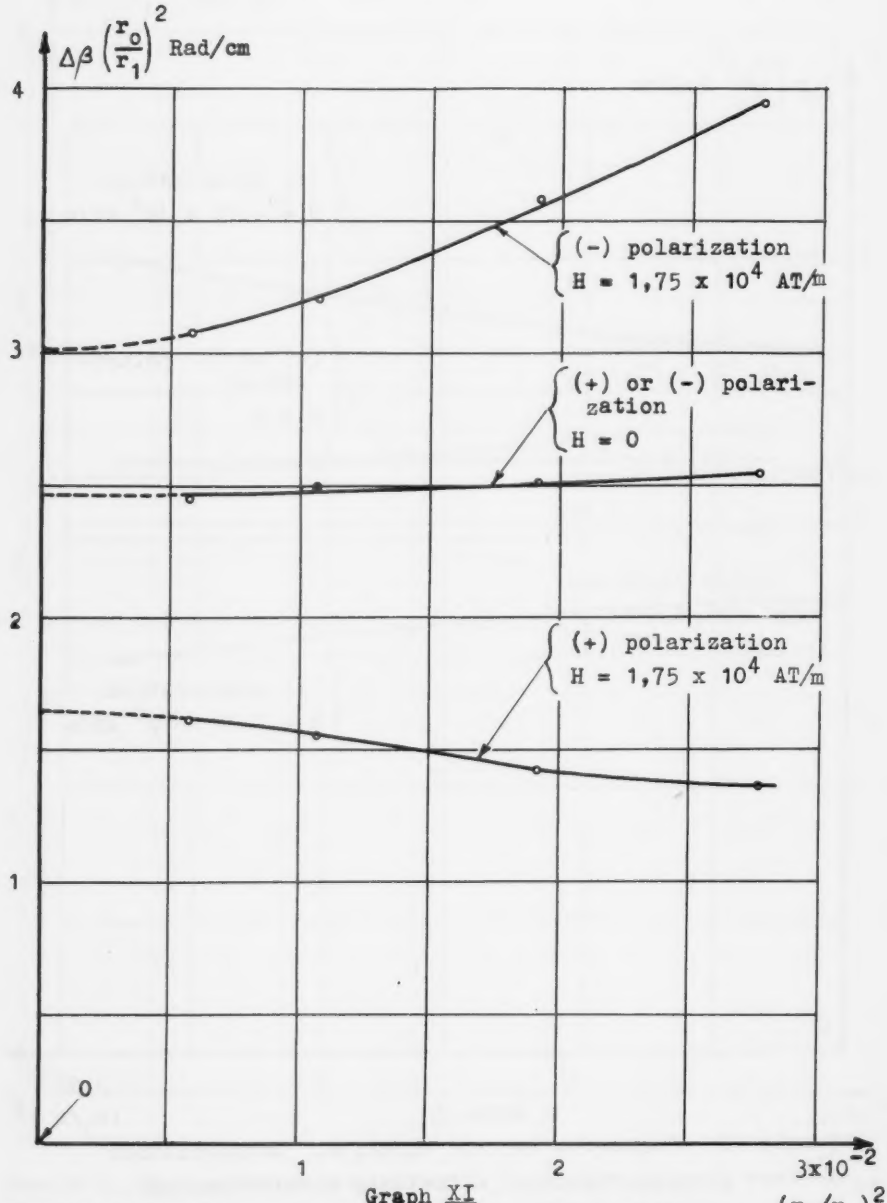
Sample I. Magnesium ferrite chromite. Extrapolation to zero ferrite radius of normalized alterations of phase constants. Ferrite radius r_1 cm, TE_{11}-waveguide radius r_o=2,7 cm. Frequency f=4600 Mc/s.

Graph IX



Graph X

Sample II Magnesium ferrite chromite. Extrapolation to zero ferrite radius of normalized alterations of phase constants. Ferrite radius r_1 cm, TE_{11} waveguide radius r_o = 2,7 cm. Frequency f = 4600 MC/s



Graph XI

Sample III Magnesium ferrite aluminate. Extrapolation to zero ferrite radius of normalized alterations of phase constants. Ferrite radius r_1 cm, TE_{11} waveguide radius r_o=2,7 cm. Frequency f=4600 MC/s

P 1705

THE LAST VOLUMES OF ACTA POLYTECHNICA ELECTRICAL ENGINEERING SERIES

(The predecessor of Acta Polytechnica Scandinavica)

Volume 7

Nr 7 GUDMANDSEN, P, and LARSEN, B F: *Statistical Data for Microwave Propagation Measurements on Two Oversea Paths in Denmark.* Acta P 213 (1957), 37 pp, 29 Figs, Sw. Kr 10: 00 UDC 621.371:621.396.24(489)

Nr 8 BOLINDER, F E: *Study of the Exponential Line by the Isometric Circle Method and Hyperbolic Geometry.* Acta P 214 (1957), 21 pp, Sw. Kr 6: 00 UDC 621.3.012:621.3.011.21

Nr 9 EKELÖF, S, BJÖRK, N, and DAVIDSON, R: *Large Signal Behaviour of Directly Heated Thermistors.* Acta P 216 (1957), 30 pp, Sw. Kr 8: 00 UDC 621.316.825

Nr 10 BRUNDELL, P O: *A New Table of the Amplitude Functions of the Iterated Sine- and Cosine-Integrals and some Comments on the Aperiodic Functions in Hallén's Antenna Theory.* Acta P 217 (1957), 13 pp, Sw. Kr 2: 00 UDC 621.396.67

Nr 11 DAHLGREN, F: *The Rationalisation in Electromagnetism and Electrostatics.* Acta P 218 (1957), 13 pp, Sw. Kr 2: 00 UDC 621.3.013:621.3.081.1

Volume 8

Nr 1 GEHLSHØJ, B: *Electromechanical and Electroacoustical Analogies and Their Use in Computations and Diagrams of Oscillating Systems.* Acta P 223 (1957), 140 pp, Sw. Kr 16:00 UDC 621.39:534.1

Nr 2 DAM, P L, RASMUSSEN, R E H, and JONASSEN, N: *On the Measurements of Electrostatic Fields and Spark Energies.* Acta P 224 (1957), 26 pp, Sw. Kr 5: 00 UDC 537.21.08

Nr 3 ALM, E: *Fractional-Slot Windings for Three-Phase Synchronous Machines and Their Properties at Load.* Acta P 227 (1957), 42 pp, Sw. Kr 5: 50 UDC 621.313.32

Nr 4 SUND, H: *A Sound Spectrometer for Speech Analysis.* Acta P 228 (1957), 64 pp, Sw. Kr 7: 50 UDC 534.784.087:621.39.001.11

Nr 5 LAURENT, T: *General Physical Laws for the Electrical Filter Ladder.* Acta P 231 (1957), 21 pp, Sw. Kr 4: 00 UDC 621.372.54

Nr 6 BOLINDER, F E: *Some Applications of the Isometric Circle Method to Impedance Transformations Through Lossless Two-Port Networks.* Acta P 232 (1957), 20 pp, Sw. Kr 6: 00 UDC 621.3.012:621.3.011.21

Nr 7 AAGESEN, J: *Polarization-Transforming Plane Reflector for Microwaves.* Acta P 239 (1957), 28 pp, Sw. Kr. 5: 00 UDC 621.336.67

Nr 8 EKELÖF, S: *The Development and Decay of the Magnetic Flux in a Non-Delayed Telephone Relay. (A Study of Telephone Relays — 3)* Acta P 240 (1957), 51 pp, Sw. Kr. 15: 00 UDC 621.318.5:621.395.64

ACTA POLYTECHNICA SCANDINAVICA ELECTRICAL ENGINEERING SERIES

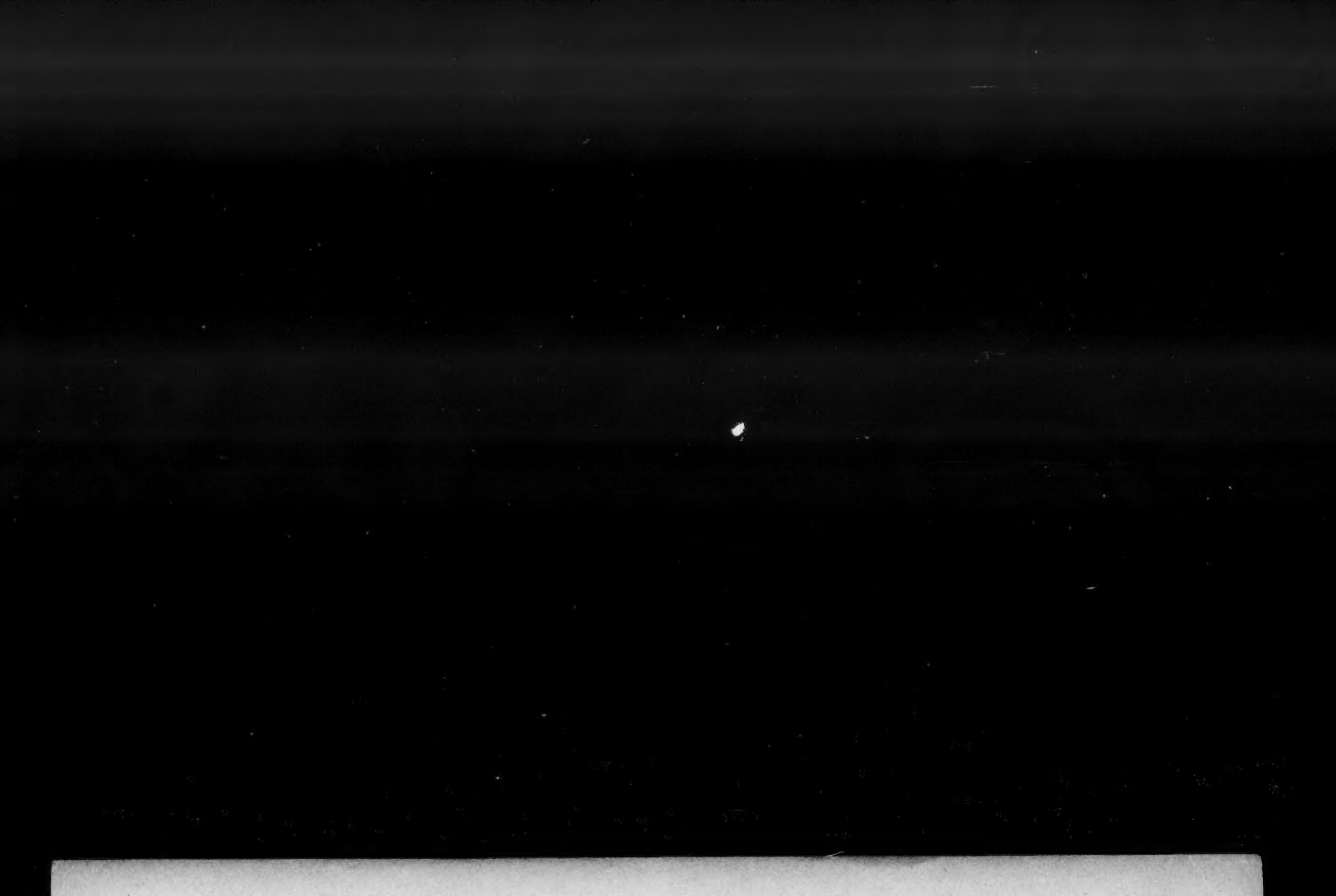
El 1 MATTILA, P.: *The Theory of the Electron Wave Tube for Elliptic Cross Section.* (Acta P 241/1958), 78 pp, Sw. Kr. 7: 00 UDC 621.385.029.6

El 2 HYVÄRINEN, L. P.: *The Autocorrelation and Power Spectrum of Nonstationary Shot Noise.* (Acta P 252/1958), 23 pp, Sw. Kr. 7: 00 UDC 621.396.82:621.287.422

El 3 ANDREASEN, M. G.: *Kurze Übergänge für H_{01}-Welle* (Acta P 253/1959), 22 pp, Sw. Kr. 7. 00 UDC 621.392.26

El 4 ANDREASEN, M. G.: *Stetige Übergänge für H_{01}-Welle mit besonderer Berücksichtigung des konischen Übergangs.* (Acta P 254/1959), 23 pp, Sw. Kr. 7: 00 UDC 621.392.26

El 5 BJÖRCK, N: *The Theory of the Indirectly Heated Thermistors* (Acta P. 255/1959) 48 pp. Sw. Kr. 7: 00 UDC 621.316.825

El 6 ROMBERG, W, KELEN, A, AND ÖSTERGREN, L: *Feldverteilung in einem dielektrischen Zylinder mit eingebetteter leitender Spirale.* (Acta P. 261/1959) 14 pp. Sw. Kr. 7: 00 UDC 621.315.619.537.212

Price Sw. Kr. 7.00